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Concurrent Engineering: Application and Implementation for U.S. Shipbuilding

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ABSTRACT

This paper reports on a SP-8 Panel project to analyze the application of Concurrent Engineering (CE) in U.S. shipbuilding and to perform a pilot implementation of CE within a U.S. Shipyard. It describes 1) results of a Shipbuilding Concurrent Engineering Questionnaire survey 2) a summary of product development performance benchmark surveys conducted at several U.S. shipyards, 3) visit to several foreign shipyards as well as Boeing Commercial Aircraft Company, Lockheed Missiles and Space Company and the Concurrent Engineering Research Center to discuss implementation of CE; 4) requirements for successful CE implementation by U.S. shipbuilders, and 4) the status of the pilot CE implementation at Bath Iron Works Corporation.

INTRODUCTION

Today the major challenges facing U.S. shipbuilders as they plan to enter the world commercial shipbuilding market are how to shorten delivery time, reduce ship prices, and improve the world's perception of U.S. shipbuilding quality.

This scenario is not unique to shipbuilding. Many U.S. industries face the same problem.

The first companies to look for a way to match world competition were in the automotive, commercial aerospace, machine tool and electronics industries. Defense oriented industries later jumped on the bandwagon with considerable assistance from the Defense Department through DARPA, the originator of the term Concurrent Engineering (CE). In the early 1990's Ingalls Shipbuilding utilized CE in the design and construction of the SA'AR 5 Frigate, Lindgren et. al., 1992, and Newport News Shipbuilding used CE on a number of development projects, Blake, et. al., 1993. Prior to that General Dynamics (GD) Electric Boat has been using elements of CE for submarine design from 1950 until today. Based on this experience, when GD embarked on their LNG program they successfully adopted a CE approach. However, at that time it was not specifically labeled as CE, Bergeson 1993.

In an effort to promote CE within the U.S. shipbuilding industry, the SP-8 (Industrial Engineering) Panel defined a project to involve a team of concurrent

engineering practitioners in working with a U.S. shipyard to implement concurrent engineering, document the implementation process and share the results at a marine industry workshop.

The objectives of the project were

1. To determine extent of Concurrent Engineering application in shipyards, the familiarity of shipyards with the use of CE and potential benefits from its application.
2. To show how Concurrent Engineering reduces time to design and manufacture a product while improving quality and reducing cost.
3. To produce a user's guide and primer for Concurrent Engineering application to U.S. shipbuilding industry as a first step to actual implementation.
4. To implement Concurrent Engineering on a specific shipyard design and construction program

The project has been broken down into two phases, an Application Study Phase and an Implementation Phase. Objectives 1 through 3 were accomplished in the Application Study Phase of the project including the development of a comprehensive User's Guide and Primer for publication through the National Shipbuilding Research Program (NSRP). Objective 4, the actual shipyard implementation, is presently being performed by Bath Iron Works Corporation (BIW), and is expected to complete during the first quarter of 1995. The implementation effort is one element of a larger MARITECH focused Development project involving the development of RoRo type commercial vehicle carriers commonly referred to as Pure Car Truck Carriers (PCTC).

This report defines Concurrent Engineering, examines how it can be used to improve and ensure a successful product development process, reviews the current status of CE application within U.S. and foreign shipbuilding industries, identifies the essential requirements for successful CE implementation and highlights current progress in the implementation of CE at Bath Iron Works Corporation.

WHAT IS CONCURRENT ENGINEERING

Concurrent Engineering is a misnomer in that it has always covered more than “engineering.” At its outset it was the concurrent design of the product and its manufacturing processes. It has grown to include all product processes from the cradle to the grave.

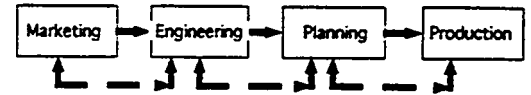
Like Just-In-Time, CE is a philosophy not a technology. It uses technology to achieve its goals.

The main objective of CE is to shorten time from order to delivery for a new product at lowest cost and highest quality. It does this by using a parallel rather than sequential process for the different functional parts of the product design. This is accomplished through the use of Cross-functional teams.

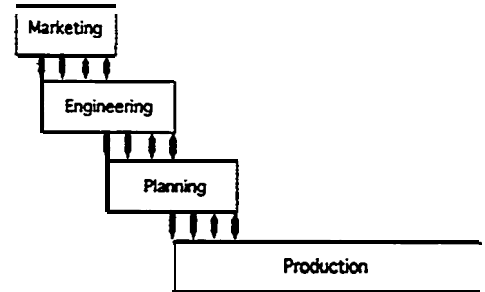
Figure 1 schematically shows the differences between the traditional sequential, overlap, parallel and the CE approaches.

The generally accepted definition of CE was prepared for the Institute of Defense Analysis (IDA) in 1986 (IDA Report, 1988), and is

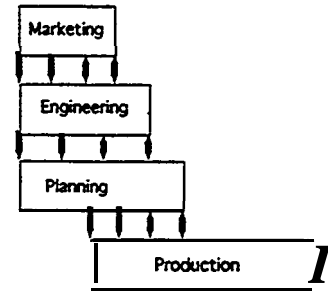
Concurrent Engineering is a systematic approach to the integrated, concurrent design of problem and their related processes, including manufacture and support. This approach is intended to cause the developers, from the outset, to consider all elements of the product life cycle from conception through disposal, including quality, cost, schedule and user requirements.



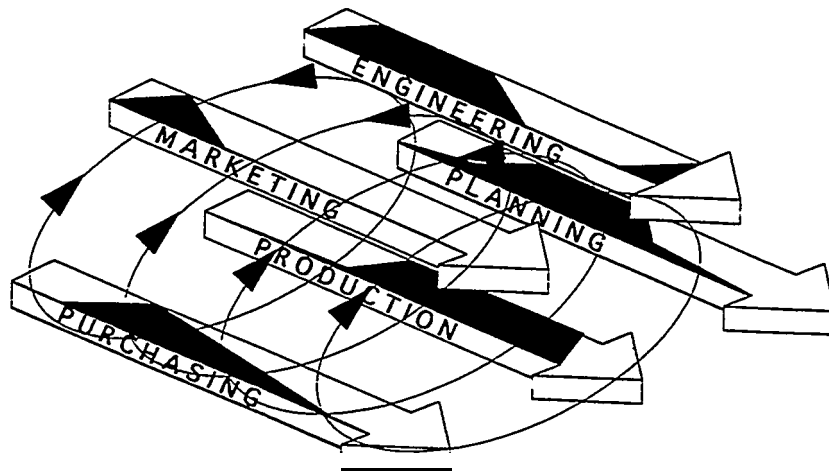
(a) - SEQUENTIAL



(b) - OVERLAPPING



(c) - PARALLEL



(c) - CONCURRENT (PARALLEL AND INTEGRATED) PRODUCT DEVELOPMENT

FIGURE 2 - COMPARISON OF PRODUCT DEVELOPMENT PROCESSES

A more recent definition from the Concurrent Engineering Research Center (CERC) (CERC, 1992) is:

Concurrent Engineering is a systematic approach to the integrated development of a product and its related processes, that emphasizes responsiveness to customer expectations and embodies team values of cooperation, trust and sharing, in such a manner that decision making proceeds with large intervals of parallel working by all its life cycle perspectives, synchronized by comparatively brief exchanges to produce consensus.

In both definitions two words are used that need to be redefined for completeness and to avoid misunderstanding. They are

DESIGN - The *development of all product attributes through engineering, planning, ordering, manufacturing, testing, operation and disposing.*
PROCESS - An *ordered series of steps performed for a given purpose.*

The most practical definitions of CE, quoted to the writer by Dr. Ralph Wood of CERC, are:

All functions work as a team in parallel, plan early, validate often and maintain oversight of product life cycle decisions within their control.

and

Concurrent Engineering is systems engineering performed by cross functional teams.

The IDA definition makes reference to involvement through disposal and the others make reference to life cycle. While this may be practical for some industries, it is not for shipbuilding. While it is true that designers avoid the use of certain materials, such as asbestos and HALON, which cannot be used due to certain life cycle problems, in general, the shipbuilder is only associated with a commercial ship until it has completed its warranty period. To make the definitions fit, commercial shipbuilders should consider delivery and completion of warranty period as their disposal. This does not mean that the shipbuilder should not attempt to take into consideration any and all life cycle information and requirements a shipowner is willing to share with the shipbuilder. It simply reflects a current fact of life. By including the shipowner on the CE team will help achieve this.

CE is customer, process and team focused. While "customer" obviously means the purchaser and user of the product, it also means the company internal users of the output from the different process involved in producing the product.

The CE approach is known by other names, such as Simultaneous Engineering, Concurrent Product Design and Integrated Product Development. Part of the reason for this is that implementers ran into cultural problems when attempting to get non-engineers involved in "engineering" or "design." It appears that the most acceptable name is Concurrent Product Development but it is the approach that is important not the name.

Ideally, CE involves all the product development participants, including the customer and the company's suppliers, in a team environment, at the start and throughout the design of the product and its processes.

CE is not new. The approach has been used by many companies worldwide for some time. Experience has shown, that, if applied properly, it will achieve its stated benefits.

Many companies that attempted to implement CE failed to accomplish it or to achieve any benefit from the attempt. In many of these cases the situation has been well researched and documented in the proceedings of conferences addressing CE. These can be read and used by other companies to help prevent the mistakes that were made by the other organizations. It is recorded in these reports that the most common reason for the failures was the inability of management to effectively manage the introduction of the required changes in their processes and their culture.

There are two basic approaches to CE namely team based and computer-based. The team based approach focuses on collocated cross-functional teams that bring their diverse specialized knowledge together at the start of a project. To be successful this approach involves significant training in team skills. While the team based approach is frequently adopted, it has many problems, such as lack of team skills, lack of experience in team management and the cost of maintaining the team.

The computer based approach attempts to provide all the tools required to accomplish the tasks in a CE environment. That is, to develop, capture, represent, integrate and coordinate the required knowledge and to permit instantaneous access to all users of the information. Real time access to shared information is a central concept of CE. It recognizes that a large number of non interfacing existing computer tools are used to develop a product design. The lack of integration of these tools is a significant problem for CE users. Consequently the interfacing of these stand alone tools is the major emphasis for the computer based approach.

Today both approaches appear to be merging into one as they both compliment each other, especially as more sophisticated computer tools are developed which

can enable the team to function more effectively. The computer tools are becoming embedded in the CE process.

Recently other computer tools, such as Computer Aided Process Planning (CAPP), Artificial Intelligence (AI) and Expert Systems (ES) are being added to the list of tools that can enable the best implementation of CE. This will ensure that all important aspects of the product design will be given the connect consideration early in the product design process and that the lessons of the past are not lost, or worse still, the undesirable ones repeated.

WHY USE CONCURRENT ENGINEERING

With the contraction in defense spending many U.S shipbuilders are planning to enter the commercial market as it is the only way they can survive. The competition is already able to develop new products in shorter time to market, at considerably less cost and at globally accepted quality levels. To successfully enter the global commercial shipbuilding market U.S. shipbuilders must change their approach to enable them to produce a high quality, competitive cost ship in the shortest possible time. Cost reductions of 30 to 50% and similar design and build cycle reductions are necessary. Obviously, to accomplish this the shipbuilders must have a backlog of ships to build or it does not make sense. To buildup the skilled manpower for such short duration shipbuilding for one or even two ships would not support long term full employment. First ship deliveries of 18 months require at least one ship per year on a continuing basis.

Realizing that this is a "chicken and egg" situation, that is, the U.S. shipbuilders cannot win international commercial ship contracts until their cost and delivery time are both reduced and this cannot occur until they have sufficient ships in their order book, it is still suggested that U.S. shipbuilders must take the initiative in implementing the necessary changes.

While the introduction of improved shipbuilding techniques, such as zone design and construction, and improved shipbuilding process through the utilization of the Build Strategy approach, have resulted in a narrowing of the gap between U.S. and best foreign shipbuilders, they are not enough. Something needs to be done to propel the U.S. shipyards to at least the level of the best competition, and then to find and sustain a competitive advantage over them.

It is suggested that concurrent engineering is a way to provide this competitive advantage. The goal of CE is to produce products that meet given function and quality requirements in the shortest possible time and lowest cost. None of the foreign competitors appear to be using all of the CE approach. So if the U.S. shipbuilders do completely implement the approach, it could enable them to catchup and pass the competition.

CE recognizes that most of the cost of a product is established early in the design stage and that the cost to make changes increases geometrically as the product progresses through the development cycle, as shown in Figure 2.

Reported benefits that have actually been attained are shown in Table I. If these improvements could be achieved by U.S. shipbuilders, they would be well on their way to successfully capturing a meaningful share of world shipbuilding orders. The reported benefits of CE (that is, lower cost higher quality and shorter design and build cycles) would appear to be exactly what is required to help U.S. shipyards attain the ability to enter the highly competitive global commercial shipbuilding market.

TABLE I
CONCURRENT ENGINEERING BENEFITS

| | |
|---------------------|----------------------|
| DEVELOPMENT TIME | 30-70% REDUCTION |
| ENGINEERING CHANGES | 65-90% REDUCTION |
| TIME TO MARKET | 20-90 % REDUCTION |
| OVERALL QUALITY | 200-600% IMPROVEMENT |
| PRODUCTIVITY | 20-110% IMPROVEMENT |
| DOLLAR SALES | 5-50% IMPROVEMENT |
| RETURN ON ASSETS | 20-120% IMPROVEMENT |

Source: Institute for Defense Analysis

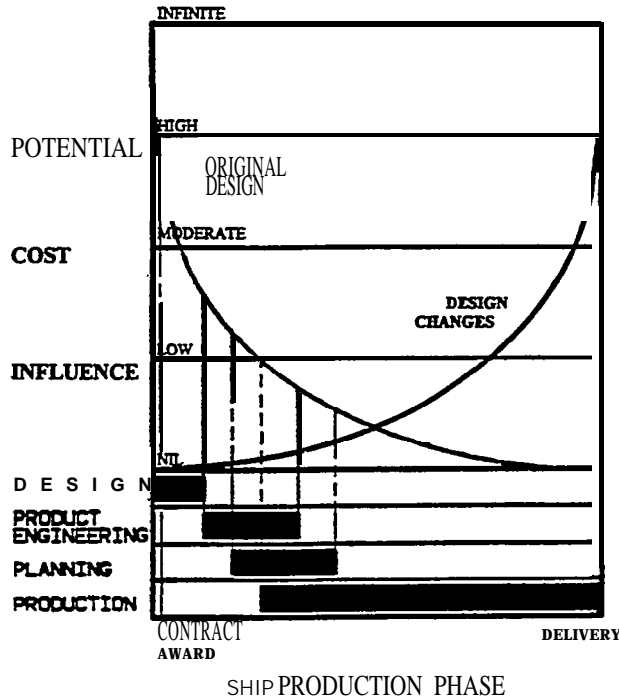


FIGURE 2 - DESIGN/PRODUCTION PHASE
COST INFLUENCE

CE eliminates the high level of rework that is normal in the traditional sequential over the wall product design process through consideration of as many

of the down stream constraints as early in the process as possible. This forces all participants to become more aware of the wider aspects of the total process and to give these aspects consideration in their areas of specialization. The potential benefits are obvious.

MAJOR CHALLENGES

CE offers a special challenge to management in that it demands significant change in the way products are developed. Management's previous experience probably has not prepared them for such a change. If a shipyard has never used CE, there will be no experience within the shipyard. Yet if the shipyard does not start to use CE, it will not gain the experience.

CE is not only the concern of engineers. CE involves fundamental changes in how a company is managed. CE will impact every aspect of a company's operation. Therefore management must take an active part in planning the CE implementation. To take part in this planning, management must first educate itself and then educate its employees.

While the use of CE is increasing, the traditional sequential "pass it over the wall" approach to product design is still the most common method. Even when the benefits that other companies achieved from CE are known, many companies or groups within companies resist its implementation. This resistance can range from the natural resistance to change, inherent in most people, to deliberate action by an individual or group based on belief that the change would be detrimental for **them**. Management must recognize this and take preventative steps.

Experience of successful CE users is that the required changes are transformational, that is fundamental, organization wrenching and far reaching. Because of this, some attempts to implement CE have failed as management and employees have not accepted the necessary changes. Some others have chosen after conducting extensive exploratory studies not to even try to implement CE because the extent of the required change was unacceptable to their management.

There is considerable knowledge, experience and research on the subject of managing successful change in a business setting (Tichy, 1983 & Adizes, 1992). While its application will not guarantee successful incorporation of change, an understanding of this information will certainly help to increase its probability of success.

The biggest challenge is being able to successfully bring about the foundation wrenching changes that will be necessary in organization structure and management.

After the CE implementation has started, management must clearly show continuing support for the implementation by providing whatever resources are necessary to make it work. When this level of support by management is seen by the employees, they begin to believe that it is the new way and want to be part of it

The next two biggest challenges are the need to change the company's culture and way of operating. They are both required and reinforce each other. The most visible is the operational change (the way things are done). However, what you see may not be real. False support by managers and employees is an insidious disease that will cause the implementation to fail. While it may seem that a company's culture would be visible, this is not so. There are many underlying and conflicting influences that result in a company's "visible" culture. It takes considerable skill and effort to analyze a shipyard's culture, but this is an essential part of the management of change. The change in the way of operating must be correctly aligned with the stated objectives of the change and must be completely supported by all levels of management. Management is the driver. If the actions of management do not reinforce the stated way things are to be done, then no matter how enthusiastic they are, employees will find it difficult to successfully implement the changes. The change in culture must match the desired mode of operating.

Typical changes require moving from

- department focus to customer focus,
- directed individual or group to coached **team**,
- individual interests to team interests,
- autocratic management to leadership with empowered followers, and
- dictated decisions to consensus decisions.

Many will recognize that most of these changes are required by any company moving from traditional management practice to Total Quality Management (TQM).

PERFORMANCE OF THE PROJECT

The following Technical Approach was used to accomplish the project objectives

- a) Performed a mail survey of a number of U.S. shipyards to determine their familiarity/use of concurrent engineering.
- b) Visited 6 U.S. and 3 Japanese shipyards to obtain detailed input on their use and interest in implementing concurrent engineering and to determine how Japanese shipbuilders achieve short building times.
- c) Conducted technical research into U.S. aerospace companies noted for their application of concurrent engineering. Also used facilities and experience of the

Concurrent Engineering' Research Center (CERC) and the Center for Entrepreneurial Studies and Development (CESD) at West Virginia University.

d) Prepared a concurrent engineering primer covering its purpose, benefits and requirements. Included lessons learned in its use by other industries, as well as determined the suitability of concurrent engineering to the shipbuilding process, and whether it could assist in bringing about the desired reduced building time and cost.

e) Prepared a users guide for the application of CE in U.S. shipyards.

f) Prepared a Final Report.

QUESTIONNAIRE

A questionnaire was prepared for distribution to U.S. and Canadian shipbuilders. Its purpose was to determine current understanding and use of Concurrent Engineering.

The questionnaire was sent to 29 individuals in 21 private and Navy shipyards. Where a shipyard had a representative on a Ship Production Panel, the questionnaire was sent to the Panel member with the request to get questionnaires to the right people and to encourage participation.

Even with the small number of questions, special mailings, and providing for stamped return, responses were received from only 6 shipyards. Five of the shipyards that responded to the questionnaires were willing to meet with the project team. Also the team met with BIW.

Four of the shipyards reported that they had used CE and that it resulted in improved performance. Three shipyards reported that they had achieved reductions in manhours, errors and rework and design build cycle times. However, only two shipyards said they were still using CE for ongoing projects. No reasons were given as to why the others were not using CE.

U.S. SHIPYARD VISITS

The project team visited BIW, Avondale Industries Shipyard, St. John Shipbuilding, Peterson Builders, NASSCO and Ingalls Shipbuilding. Each visit lasted a whole day. A proposed agenda was sent to each shipyard prior to the meetings. The project team first met with the shipyard meeting coordinator and discussed the agenda and answered any questions about the visit. Then the team was given a brief tour of the shipyard. Next small group meetings were held with the different shipyard departments such as Marketing, Engineering, Planning, Purchasing and Production. The objective of these meetings was to give the team the opportunity to evaluate the shipyard's concurrent engineering involvement and to help select topics to be

covered in the formal presentation on concurrent engineering. At the start of the formal discussions the team presented background information on the project such as goal, objectives and approach. The formal presentation was based on material developed by ICD and each attendee was given a presentation workbook. Since the shipyard visits, Mr. Huthwaite has written a book (13) which covers everything presented at the CE overview, and more.

Almost every shipyard asked for examples of CE metrics. Although a few were briefly discussed, there was not enough time to clearly describe or fully document them. This has been partially done in B. Huthwaite's book (Huthwaite, 1994) and in the CE **PRIMER**. A very detailed approach to selecting suitable metrics for CE is presented in the CERC Report, **PROCESS ISSUES IN IMPLEMENTING CE (CERC, 1993)**.

After the formal presentation on concurrent engineering, a benchmarking tool was described. The shipyard attendees were then split into multi-disciplined groups of three to five people and benchmarked their shipyard considering 20 characteristics with 1 representing a low CE involvement to 10 representing complete use of CE. They first did this individually and then obtained consensus in the groups.

The team scores range from a low of 2.35 to a high of 6.25 with an average of 3.7. The shipyard averages range from a low of 2.59 to a high of 6.0 with an average of 4.0. The team also scored the shipyards based on the information gleaned from the morning face to face meetings and feedback during the formal CE presentation. In general there was good agreement between the team's scores with the lower scoring shipyards and low agreement with the higher scoring shipyards. While it is encouraging that *one* shipyard benchmarked itself on the average as a 6, and another shipyard had one team that benchmarked itself as a 6.25, the team did not see any practices or processes that would justify these high scores.

The general industry experience has two levels, one for designers from 3 to 4 and one for managers from 5 to 6. The majority of the shipyard results are similar to the designer range, but this is not a good match as most of the shipyard participants were managers. This means that the shipyards are further behind U.S. industry in their readiness for CE. However, the scores for industry in general are not very high and reflect the fact that the number of companies using CE is still small compared to the total number of companies!

The group were then asked to write down three questions on concurrent engineering and at least one question from each group was answered as a way to develop further discussion. Most of the questions related to teams. All the questions will be used as subjects to be covered in the development of the **CE USERS GUIDE FOR SHIPBUILDERS**.

Four of the shipyards that reported they used CE actually only used some of the CE approach, namely early involvement of production in the design process and parallel processing. Customer focus and use of multi functional teams were not clearly demonstrated. Also the "design review mindset" still exists in even these shipyards, and many "people" problems still have to be resolved. There are many functional managers who will not agree to the changes that CE requires, especially the elimination of internal politics and power-plays, and the building of trust and effective teamwork between all participants.

Most of the shipyards had used a parallel development approach for some time. The ongoing thrust was to involve the downstream participants in the total product development cycle as early as possible.

All of the shipyards reported that their biggest problems were getting the right people at the right time and for the time required. Production people were usually too busy with today's problems to spend time to develop work that they would not see in the yard for a year or more. Also, different people were sent to participate based on commit availability rather than on value. Another problem with those that had applied some of the CE/teaming approaches is that everything worked well as long as there were no crises. As soon as problems or conflict arose the people tended to move back into their old methods and alliances. The solution to these problems is management direction, communication and reinforcement of CE principles, and education and training of everyone involved, from the top down.

FOREIGN SHIPYARD VISITS

Mr. Tom Lamb visited three Japanese shipbuilding company design offices and /or shipyards at the end of May and early June 1994. The companies were Ishikawajima Harima Heavy Industries (IHI) design office in Tokyo, Mitsubishi Heavy Industries shipyard in Nagasaki and Sumitomo Heavy Industries shipyard in Oppama.

All shipyards were familiar with the term Concurrent Engineering and its meaning, mainly through reading English language books. However, none of the shipyards currently use much of the CE approach, nor do they utilize cross-functional teams, and yet they achieve some of the shortest design and build schedule times in the world. How do they do this

The short schedule duration's for time on the berth or in the dock, which range from 4 to 6 months, for commercial ships, are obviously dependent on erection crane capacity, space to construct large erection blocks, and the maximum use of advanced outfitting. The ability to start erecting a ship in the dock beside another ship already under construction, is also a big factor. That this is the case can be seen when it is considered that some single berth or single dock

Japanese shipyards can complete 5 to 6 ships in a year, and with 4 month erection times this means that there must be berth or dock time overlapping.

Surprisingly, the Japanese take a longer time after sea trials to deliver the ship than do some European shipyards. This may be because the Japanese choose to wait until after sea trials to completely clean the ship and perform all painting touch up, whereas the Europeans have the ship in the final delivery condition prior to sea trials.

All of the shipyard design groups are functionally organized, although some changes are underway. There appears to be little experimentation with cross functional teams or other "innovative structures to improve job satisfaction and empower the employees. However, it may simply be because they see no need or benefit from these options. The current close relationship between departments, teamwork and supporting (non-conflict) approach to their work appears to eliminate the need for cross functional teams. While some of the organizational options could be beneficial to both worker and employer this matter is not considered the best target of opportunity at this time.

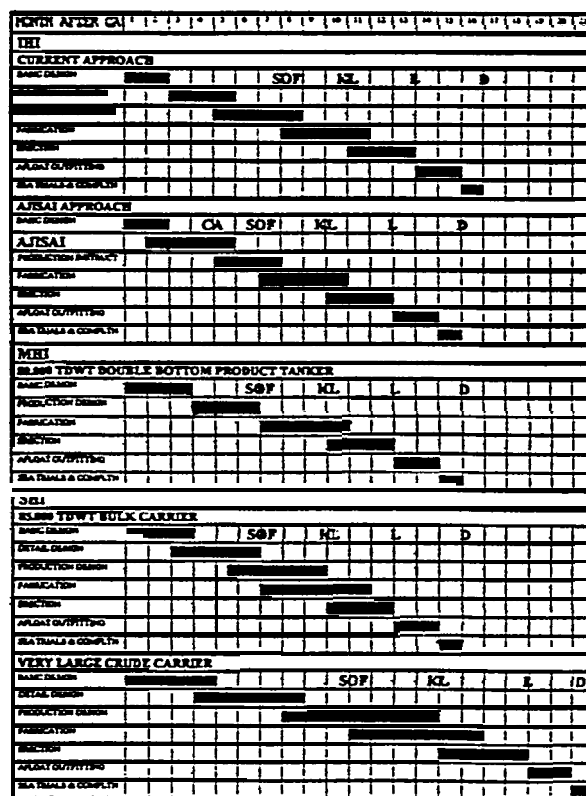


FIGURE 3 - TYPICAL JAPANESE DESIGN AND BUILD SCHEDULES

It should be noted that, even in Japan, the design and build cycle time for naval ships ranges from 3 to 4 years. This is because it is based on government

funding schedules rather than what is the most efficient design and build time for the shipbuilder. Obviously, the government funding schedule has been established over many years and apparently gives a satisfactory outcome to the Japanese Navy.

Japanese shipyards involved in both naval and commercial shipbuilding do not mix in the same shipyard naval ships with the large tankers, bulk carriers and container ships. However, at the shipyards where the naval ships are built they also build high work content smaller ships such as ferries car carriers, small product tankers and handy size bulk carriers and LNG ships. This seems to be as much to provide a continuous manning level as it is related to any similarity in the needs for naval and the other types of ships. In the case of dual purpose shipyards, even the Japanese have the same problems that have been identified for U.S. shipyards planning to do commercial work while continuing their naval work. That is, how to effectively handle the different requirements for documentation worker skill levels and quality control.

All three of the companies visited are widely diversified in the international "heavy industry" market. While shipbuilding used to be the major part of their business, it is now only a small part. of diversification are bridge building, land power plants, desalination plants machine tools and aerospace. Another interesting point is that none of them are shipowners like many of the successful Scandinavian shipbuilding groups. However, they do have contact with groups of shipowners through their banks, trading houses and intercompany directorships.

Figure 3 is a summary of typical design and build schedules for the companies visited.

VISIT TO CERC AND CESD

Mr. Tom Lamb visited both the Concurrent Engineering Research Center (CERC) and the Center for Entrepreneurial Studies & Development (CESD) at Morgantown West Virginia on May 2 and 3, 1994. CERC has been developing CE tools and assisting companies to implement CE since 1989. CESD has been helping government and private companies to implement Total Quality Management and effective teams Since 1981.

In the morning of the first day, CERC showed a video and gave a general presentation on their formation, achievements, current activities and future plans. A demonstration of the CERC groupware to facilitate Virtual Collocation of CE teams was also given. The system involves video, audio, on line shared information, and the tools to permit many users to interface in real time.

Since 1993 CERC has decided to concentrate on developing computer tools/systems to enable CE. They no longer provide any training or on site CE assistance. Fortunately, this has been taken over by CESD who

will perform CE Readiness Assessments, Team Training and CE Implementation support.

CESD is currently involved in a number of implementation and team launch projects for both private and government groups. CESD could certainly help shipbuilders to assess their current readiness for CE and to perform a pilot implementation.

VISITS TO BOEING AND LOCKHEED

A visit to Boeing Commercial Aircraft Company was arranged in conjunction with an SP-4 panel meeting in Seattle on October 6, 1993. All members of the panel were invited to visit the Everett facility in the afternoon for the regular plant tour. In addition, a **special** presentation was given by the Boeing Publicity Department on the application of Concurrent Engineering and the use of 3D digital product model for the new 777 aircraft. The formal presentation described the need that forced Boeing into an improved approach and covered the highlights and achievements. Because of the approach, the 777 was Boeing's first aircraft that was built without the use of full scale mock ups. Also, it was anticipated that the approach would eliminate the months of system testing and rewiring that they traditionally had to perform after the prototype aircraft was turned over to the test group.

In the morning the team met with Mr. Ted Scoville the Boeing Concurrent product Development Manager who had the responsibility to overview the Concurrent Product Development (CPD) activities and to make it work. Mr. Scoville reported that Boeing had achieved significant benefit from the implementation of (2PD) but that people problems had prevented it from achieving its full potential.

He offered the following lessons learned

- Computers and 3D product modeling facilitated change required for CPD.
- Biggest implementation challenge was peoples resistance to change.
- Success of teams will depend on _management control or lack thereof.
- Cannot apply CPD partially to a project. Must be all or nothing.
- Figure out a way to work within line organization without creating a new line organization for each product.
- Guard against non-design participants getting too involved in design.
- Middle management see CPD leading to job loss and breakdown in authority. Because of this teams are resisted by traditional middle managers.

- Organization must be made to fit the process.
- Top management must clearly state who the team members are working for and make sure the functional managers accept their new role.
- Teams must work hard at being a team otherwise they will drift back to traditional process.

The team also met with Don Norling, the Integrated Product Development Leader for the Missiles Systems Division (MSD) of Lockheed Missiles and Space Company on March 1, 1994.. MSD started using Integrated Product Development (IPD) in the 1980's. IPD has been applied on a number of programs with resulting benefits in quality, cost and schedule. Success is directly attributable to the fact that the second most senior executive in the company was the sponsor of the activity.

In late 1990 MSD established a team from different parts of the company to look at their development needs. Computer tool development was being developed by the Space Division and the MSD concentrated on the people side culture, teams, etc. The team, consisting of 3 full time and 12 part time members to develop and facilitate IPD in MSD. The team arranged for workshops from Bart Huthwaite covering CE and his Strategic Design approach. They prepared extensive promotional material including Users Manuals, and educational materials. MSD has a very impressive IPD Training/Conference room in which most of its material is on display. MSD are no longer in an IPD selling mode. IPD is accepted throughout the division and the challenge is now to keep up with demand for service and to ensure that programs and teams do not start without necessary training and preparation.

Mr. Norling offered the following lessons learned

- Many people believe they are already practicing IPD, but they are not
- Not aware of any company that has completely made IPD their way of business.
- Hardest group to bring onboard is engineering as they perceive a loss of status. Others are on the team as co-partners.
- Very difficult for others (production) to change from design reviewers to participants.
- Must get agreement in writing up front on the conflicting roles of Project Management Functional Management and Product Development Teams.

- Make IPD success part of performance appraisal.

Make sure teams know the difference between empowerment and autonomy.

- Use team contracts, charters and memorandum of understanding to facilitate communication and collaboration.
- Take time to train the teams and give them time to plan their activities.
- Have an IPD champion.

IS YOUR SHIPYARD READY?

Once it is determined that CE is a suitable approach for a company to help it improve its operations, it is essential to see if the company is ready for CE. That is, is the company culture, practices and technology suitable for the transforming changes that are required?

Fortunately, others involved in the development of CE have recognized this need and have prepared various approaches to help companies answer this question. One such approach is the **PROCESS AND TECHNOLOGY READINESS AND ASSESSMENT FOR IMPLEMENTING CONCURRENT ENGINEERING** developed by CERC (CERC, 1992& 1993). This approach is based on the obvious premise that you need to know where you are before you can successfully set off in a specific direction and get to a desired destination. It uses the CE critical elements and process maturity stages, as well as the enabling technologies and their application level to map on a spider diagram a company's current CE readiness, such as shown in Figure 4.

Another assessment tool which does provide a measure of where you are and where you want to be as well as providing a "road map" of how to get there was presented in the book **CE CONCURRENT ENGINEERING: THE PRODUCT DEVELOPMENT ENVIRONMENT FOR THE 1990'S** (Carter, 1992).

By following the process described in the report a company can determine if it is "ready" to implement CE. The process will also indicate where any changes must be made before implementation should be attempted. Unfortunately, no guidance is given as to what would be an acceptable readiness level to assure successful implementation.

Although an assessment may seem like a very involved process, it is not and performing the assessments can prevent wrong decisions and later time delay and costly revisions to the implementation process.

TEAMS

The use of teams in the workplace is not new. It probably goes all the way back to the earliest application of a number of people to a specific task.

Many books and articles have been written on teams. The intent herein is not to even try to discuss the many specific aspects of teams, but rather, to concentrate on their application to CE.

Teams generally form when it takes more than one person to accomplish a task. The use of teams is usually beneficial. Successful teams use the synergy of their members to accomplish more and better things than a group of individuals not working well together.

A major characteristic of CE is the use of cross-functional teams, integrating the concurrent development of product and process design. In fact there is no CE if there are no cross-functional teams. Unfortunately, this is the most difficult part of CE. However, if the use of cross-functional teams can be successfully developed, the other requirements generally fall into place.

It is important to differentiate between teamwork and teams.

Teamwork occurs when individuals in a group or organization behave in a cooperative manner with all other individuals for the benefit of the group or

organization as a whole. Teamwork does not require teams.

Teams are groups of people established to accomplish a specific purpose.

A team is a group that visibly shares a common purpose, and recognizes it needs the efforts of every one of its members to achieve this.

There are many types of teams, such as:

task team,
tiger team,
cross-functional team, and
Self-directed team

There are some implementers of CE that insist that collocation of the cross-functional teams is essential for successful use of CE. Then there are others who claim that the attempt to collocate team members led to the failure of their CE implementation due to lack of functional manager support and team members lack of

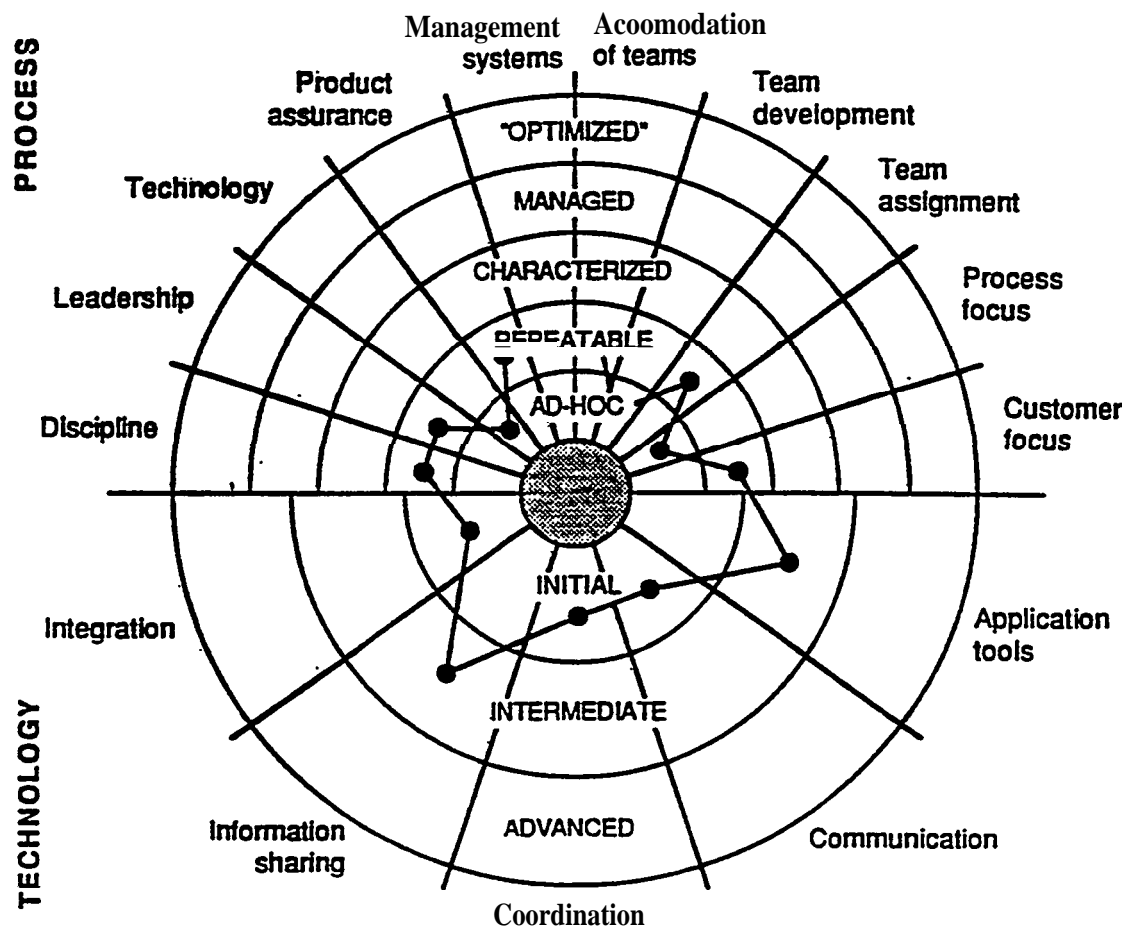


FIGURE 4 - CE READINESS ASSESSMENT DIAGRAM

functional belonging. What should be done? Probably, all the members of a CE pilot project team should be collocated. As CE is applied to other projects the team core members should be collocated. As CE becomes established in a shipyard and the use of computer tools is increase a move to virtually collocated teams can be made.

The CE process requires. real time interactive, ” integrated, and unconstrained input from many traditional functional specialists from the start to the fish of the product design. The most effective way to achieve this is to group the functional specialists into a team whose purpose is to accomplish a given assignment Such a group is a cross-functional team. Its members are generally of similar level in the organization’s hierarchy.

It is essential that a team be given training in how to operate as a team. Otherwise it will spend most of its time trying to find this out and probably will never reach it. So many times’ people are simply thrown together into a group, and told that **they are a team**, without being given any team training. This is obviously the wrong way to implement teams and could jeopardize the future of whatever propose they were formed

Training should be given on team skills such as communication emphasizing listening skills, group

decision making, conflict resolution as well as specific CE skills. In addition, the team members should be given clear direction on how the team fits into the existing organization structure and whether changes are planned.

IMPLEMENTATION

Having determined that CE is the right way to improve the company’s performance and that the company is ready, the next step is to implement CE. Once the readiness status of the organization is known, this information can be applied to determine what strategic (process oriented) and tactical (tool oriented) decisions need to be made to implement CE.

As stated above, the implementation of CE by a shipyard will involve fundamental changes. The most obvious change is the way the product development is performed. Well established “comfortable” approaches must be replaced by new approaches. Other, not so obvious, changes are also required. me shipyard’s existing culture, technology, organization and operational methods will all need to be realigned to support the new product development processes.

Of these, the culture, will be the most difficult to change. Complete trust openness, cooperation and

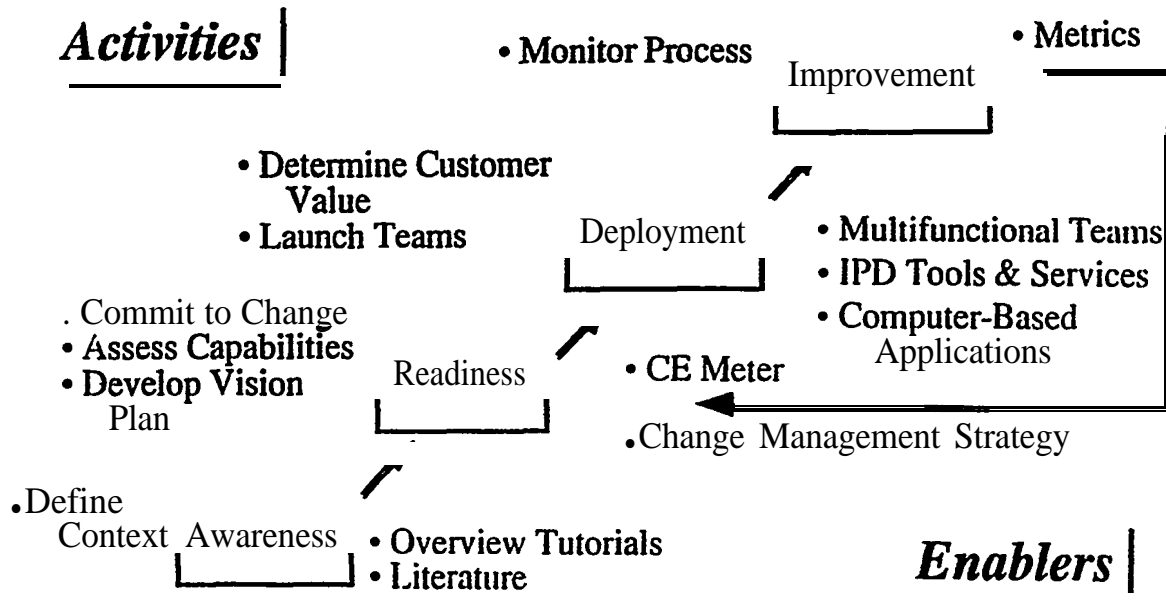


FIGURE 5 - CE IMPLEMENTATION

collaboration cannot be imposed on a shipyard. They must be earned and that takes effort and time. This is why an assessment of current status of these aspects is so important and must be done before any attempt to implement CE is undertaken.

The big question is what should be tackled first? Should the **cultural changes** be made before the product design process changes or vice versa? If a lot of time was available changing the culture first maybe the best way. However, time is usually not available and the best approach appears to be the concurrent development of both the new culture and product design processes.

Management and employees must believe that implementing CE will improve the company's performance. Because of this, most companies introduce CE as a small pilot project that can quickly show the benefits. A shipyard should carefully select the project and CE implementation team to give the best chance of success. Then they can build on this success in stages by using members of the successful pilot project team to be "champions" for new project teams.

Seeing is believing, so the best approach is to get people involved in actual projects. However, the team members must be given the training necessary to help them function correctly in an actual CE project. Without the required training, the outcome will be uncertain.

As CE is not a single event but a continuous journey, the final part of the implementation process is continuous **IMPROVEMENT** of the product and the design process by monitoring and measuring the product design process. Figure 5 shows this approach with the **ACTIVITIES** and **ENABLERS** at each stage, as well as the feed back loop for continuous improvement.

Barriers to Implementation

CE is a non-traditional approach to the product development process, and while many of its concepts are logical, its implementation may be perceived by many as radical change and thus generate significant barriers to its acceptance and support. There are both organizational and technical barriers. Organizational barriers are probably the most difficult to remove as they can involve deep seated beliefs and values, management style, structure and policies. Technical barriers are the result of inadequate enabling technologies and knowledge to facilitate the implementation of CE, such as accessibility of all users to the product model and instantaneous sharing of information. Organizational and technical barriers are interrelated and this adds to the complexity.

As with any plan to implement change, it is essential to know where the barriers to the intended change are, so that they can be lowered or removed. In spite of the reported benefits of CE, it has met great resistance in many places. The reasons for this

resistance are many and complex. Some of them have been identified by previous CE implementers and include

- Lack of well defined measurable and repeatable approaches to the effective implementation of CE.
- Unwillingness to undertake the significant changes to status quo required by CE.
- Don't know how to fit CE approach into existing organization.
- Management and workers lack of experience and knowledge of how to operate as teams.
- Team member lack of customer interface experience.
- Perceived threat to functional managers position and authority
- Lack of CE knowledge and experience.
- Lack of top management support.
- Unsuitable organization culture.
- Inadequate time allocated by top management to support CE.
- Accounting systems not able to support CE approach.
- Individual performance appraisal and reward systems.

To overcome these barriers a plan must be established and each one taken care of. CESD have used the Quality Function Deployment (QFD) process to develop this type of plan for a number of clients. However, it is not easy, nor certain of success. As Machiavelli stated, many years ago, in "**THE PRINCE**," implementing change is very difficult due to lack of support from people, and never is certain of success.

Common Failure Modes

A excellent discussion of this aspect of CE implementation was presented by Parsaei and Sullivan, 1993. Figure 6 is taken from that reference. It shows the many modes of failure and their relationship to the phases of implementation as well as the influence of management and employees at each mode. It should be noted that the items listed were all lacking and thus led to failure of the implementations. The chart can be used as a failure avoidance plan for implementation teams by ensuring that each mode is correctly and adequately considered. Regular review and comparison to the teams own experience may enable them to avoid the usual problems.

Lessons Learned

There have been many implementations of CE throughout the world. There have been failures as well as successes. It is normal to report on the successes and not the failures and this has been done at the many conferences and in publications. However, even the successful implementations were not problem free. From these reports it is possible to develop a list of lessons learned. First the elements that appear to enable success and then the things to avoid will be listed.

Lessons for Success

- The reason or need for the change to CE should be shared with all participants.
- Assure that all participants have a

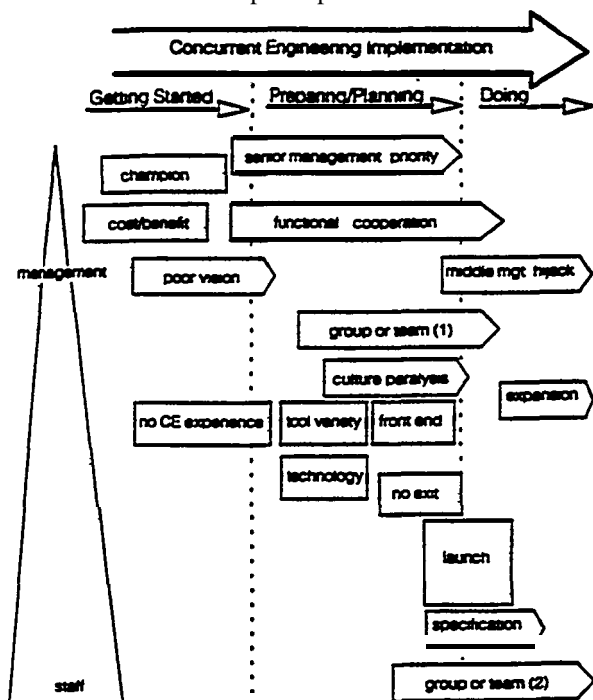


FIGURE 6- CE COMMON FAILURE MODES

- common understanding and definition of CE.
- Gain personal experience by performing pilot projects.
- Carefully select pilot project. It should be real, visible and achievable in a short time.
- Build on pilot project success by forming more pilot project teams after each successful pilot project completion.

- Use enthusiastic successful team members to assist faltering teams and convert doubters.
- Select best personnel for Pilot Project Team(s).
- Institutionalize successful CE implementation. Ensure CE becomes part of the shipyard culture.
- Sell the approach from the top down - The vision has to come from the top. However, implementation must be from both the top and bottom. Commitment must be shared from the top to the bottom.
- Use a CE Steering Committee for top/middle managers who can become CE champions.
- Use a member of the Steering committee as the sponsor for product teams.
- Production role must be clearly defined up front to prevent them from simply extending their customary "design review" role.
- Train cross-functional teams not functional groups.
- Training of teams in team skills must be completed before team starts on the actual product design process.
- The organization structure must be changed to fit and support the CE process.
- Let the new CE team(s) visit established teams to see the results and how others apply CE.
- Functional managers must be trained for their new role.
- Functional managers should be involved in defining their new role.
- Reward system must encourage team success and not individual performance.
- Use frequent top management reviews to keep them involved in process and share ownership of decisions.
- Both customer and major suppliers must be involved as full team members.
- Develop and get management and team agreement on metrics that measure product and process quality and performance before the product design commences.
- Team must develop its operating process before starting product design process.

- Team goals and operating boundaries must be clear.
- Teams must continually measure how they are performing as a team.
- Use a comprehensive CE Implementation Plan for each pilot project until CE is institutionalized in the shipyard.
- Establish shipyard wide guiding principles and values.

Things to Avoid

- Partial implementation of CE. Must select a slice through the complete organization involving as many of the departments as possible for the team rather than just a few “important” departments.
- Changing tools and information without - - C h a n g e s .
- Management understating extent of change required to successfully implement CE.
- Management sending mixed signals about CE - saying one thing but doing another.
- Failure to remove/replace problem members in (CE teams).
- Mockery of delegated authority by management over-riding team decisions
- Functional management constraining cross-functional team members by insisting they be consulted before members make decisions.
- Ignoring the customer.
- Ignoring the suppliers.

Metrics

The need for metrics in implementing CE should be obvious. Without them improvement changes cannot be verified and the management of the CE process cannot be monitored and will be ineffective. All the reports on CE “lessons learned” clearly state the essential need for appropriate metrics to be available up front and used in the CE implementation process. And yet very few reports, articles or books on CE give good examples of suitable metrics. They state that both the product quality and process effectiveness must be measured but they do not say how! Where examples of metrics are given they are “macro” measures and not specific enough for the performance of the CE processes to be completely assessed.

A metric consists of two or more measurements or single data points. For example, product design manhours is a measurement but the comparison of current product design manhours to previous product design manhours is a metric.

The lack of a commonly accepted CE process, lack of measurement standards or even norms and the multi-faceted interface complexity of CE, add to the above problems to make the development and use of CE metrics very difficult.

CE metrics must address the basic tenants of CE, namely,

- integrated product and process design
- concurrent product and process design
- meet customer requirements,
- use -cross-functional team, and
- consensus decision making

Metrics should be;

- Simple,
- easily obtained,
- objective - different people assign same value to the metric,
- valid-measure what is intended,
- robust - insensitive to small changes in product or process, and
- provide a basis for predictive process modeling.

Metrics can be “off-line” (pre/postprocess) or “on-line” (in process). On-line metrics are more useful as they provide an active control of the CE process. Obviously, they can be both qualitative or quantitative. CERC divided metrics into primary and secondary types. The primary metrics are the major areas of concern for CE, namely product quality, cost and cycle time. These measure the outcome of the product development process. The secondary metrics measure how well CE is applied or the effectiveness of the product development process.

Once the metrics are developed it is still necessary to decide how the information will be collected, the metrics computed and the results used. Also, for special metrics developed by a shipyard, the question of validation must be answered.

Notwithstanding these problems with metrics, it is better to have invalidated metrics than no metrics. As the metrics are applied over time they can be refined.

Useful measurements are

- customer satisfaction,

- product cost,
- time to market,
- product design manhours,
- product design time,
- process design manhours,
- process design times,
- number of engineering changes,
- duration of time changes,
- manufacturing manhours,
- manufacturing time,
- number of quality defects,
- product design manhours for rework
- process design manhours for rework,
- manufacturing manhours for rework,
- functional integration - number of functions involved in product design
- time to reach team consensus,
- number of meetings to reach consensus,
- team commitment and
- number of new products launch per year.

These measurements can all become metrics by comparing current value with past values. Other CE process metrics are ;

- concurrency index,
- common understanding ratio,
- team dispersion index
- requirements stability,
- process response,
- management involvement
- plan compliance,
- communication index
- conflict index, and
- information sharing index.

In order to compare the performance of different CE projects, “normalizing metrics” can be used. These compare the product Complexity, such as number of functions involved, number of components, number of team members and managers that really know how the product works and project Capability, such as number of people involved, number of teams, management organization and dispersion of teams and their members.

Implementation Framework

CERC and other implementers of CE have established processes that encompass many of the

lessons learned listed above. Combining these processes provides a framework for a CE Implementation Plan.

The framework is

1. Train Top Management - CE and Team Dynamics/Skills.
2. Establish CE Steering committee.
3. Select Potential Team Members.
4. Train Potential Team Members and Functional Managers - CE and Team Dynamics/Skills.
- 5 . Perform CE Readiness Self-Assessment
6. Determine required changes and improvements to be ready to implement CE.
7. GO -NO GO decision.
8. Initiate required Organizational and cultural changes.
9. Assign a Steering Committee member as Pilot Project Sponsor.
10. Select Pilot project
11. Create Cross-functional Team.
12. Team designs Team Operating System.
13. Current Product Process Captured and Analyzed by Team.
14. Team develops Team Metrics.
15. Team decides CE Tools to be used.
16. Team develops Pilot Project Plan.
17. Team presents Goals, Metrics and Plan to Sponsor and then Steering Committee.
18. Perform regular Self—assessments of Team Performance against selected Goals, Metrics and the Plan.
19. Apply ‘lessons learned’ to other projects to continually improve the CE Process.

INFORMATION SYSTEMS REQUIREMENTS FOR CONCURRENT ENGINEERING

A generic information system is impossible to precisely specify for Concurrent Engineering. This is because each business entity, and specifically, a shipyard, has its own unique legacy systems in operation. These must be individually accounted for and realistically optimized for return on investment. Therefore, it is only possible to broadly describe the information system attributes that a shipyard should consider in implementing a Concurrent Engineering methodology. These will include systems able to communicate with each other, as well as with customers and suppliers systems. The systems must maintain accurate and controlled records of all

transactions, design reviews, production schedules, problems, and issues. They must provide data to the entire Concurrent Engineering Team in real-time as requested.

An appropriate information system must be adaptable to evolutionary changes. It should be no more rigid than the engineering and manufacturing process it is designed to control. The design environment of tomorrow must be "Accessible, Flexible, and Open." An open environment is the ability to handle a heterogeneous set of design tools, that is, the ability to handle co-designs by combining or linking tools from different disciplines together. This is called Integration Software.

Information links in most U.S. shipyards between engineering and manufacturing are still sequential. In advanced companies, research product development and the design of manufacturing processes are carried out concurrently so that knowledge from one area can readily influence decisions made in other areas in real-time. An information system must be capable of Parallel interfacing and simultaneous information sharing. The objective is to provide a seamless, homogeneous flow of information to all interested parties who have the ability to react and interact in real time.

The impact of concurrent engineering emphasizes the design through the build integration cycle of the overall product and process. New information systems are needed having ability to access this information. New access methodologies must be developed that also attempt to develop layers of information. Systems need to provide the ability to access bits and pieces at higher macro levels so that the teams can recognize whether the data stream has value. The concept of Information Systems has changed from one of management control to one of information sharing.

What is needed is cost effective solutions to sharing information based on reduced time to market (product introduction cycle time), a "do-it-right-the-first-time" attitude (design quality), and a focus on involving all organizational functions all the way through the product cycle (information constantly shared cross-functionally). The data processing characteristics of the personal computer with the transaction-processing capabilities of today's mainframes need to be connected. The extreme maintenance costs of computing must be lowered and the productivity realized by their use increased. An information strategy must be put into place. Information organizations must be driven. They should not be the drivers.

The approach of choice, is an *Open System*, designed for *Accessibility, Flexibility, Parallel Interfacing, Relational Data Base Storage*, and *Libraries of Information* for Technology Re-Use. *Application Frameworks* also to allow for multiple application software and mixed CAD/CAM/CAE tools, with some degree of access and monitoring should be included in

any CE IS System. Interoperability, scalability for the future, and *availability* to cross-functional inquiries are key attributes. The ability to *set standards for application* and change hardware as capability needs warrant (speed storage, network server needs, etc.) are other key attributes.

Therefore, the recommendation for a CE Information System will most likely require a paradigm shift to an *Integrated Client-server Information System*.

COST BENEFIT ANALYSIS

Actual cost benefits of CE are not widely shared. This is understandable as it may be either an embarrassment to a company, if not good, or a competitive advantage to a company, when it is good. It may also because they are not easily measured, especially with normal accounting methods. Activity based accounting should help but only if the activities are set up for CE.

Cost benefits are reductions. The reduction can come from the direct benefits of improving a design, better material selection and work content reduction as well as the indirect benefits from shorter product development cycles. For the latter, there are obvious cost benefits from the application of known fixed costs and other overhead costs due to the shorter duration to which they are applied. But there are also unknown cost benefits from getting to the market quicker, better quality, greater customer satisfaction, etc., which are difficult to assess.

Most proponents acknowledge overall cost reduction from the use of CE, mainly due to reducing product cost through better design and eliminating rework due to bad design decisions and design errors.

An attempt to develop better knowledge of the cost impact of CE was performed by TRW (Nichelson, 1991). They looked at four different products on which some of the CE approach was used. It can be seen that the Benefit/Cost ratio increases directly with extent of CE applied and also with number of personnel involved. The latter is surprising as CE could be expected to become more difficult with larger groups. On the other hand, it may be because the implementation of CE results in a structured approach with tools to improve the factors that normally become more difficult with size, namely, sharing information communication, etc. Benefit/Cost Ratio varied from 2.8 to 8.6, which are very significant.

IMPLEMENTATION OF CE AT BATH IRON WORKS CORPORATION

As with most shipyards, elements of CE have been part of the evolving product development process at BIW for a number of years. In particular, past focus has been on involvement of shipyard planning and production engineering functions in the design process,

overlapping design and production phases of product development, application of enabling technologies such as CAE/CAD/CAM, and more recently the use of teams in management of the product delivery process. In addition to the CE pilot described in this paper, a number of other ongoing projects at BIW have implemented best practices identified through CE benchmarking and technology transfer with industry leaders. The CE pilot described herein represents an intensified and focused effort to implement all of the essential elements of CE within a single project and to thereby lay the foundation for broadened understanding and institutionalization of these practices throughout all future product development efforts.

SELECTION OF A PILOT PROJECT

The CE Pilot implementation began with the evaluation and selection of a pilot project in December, 1993. Numerous candidate projects were ongoing or proposed including barge mounted electrical power generating plants, lubricating oil purification modules for shore-based electric plants, a small coastal combatant ship, a MARITECH funded multiple ship design project and a major upgrade to the DDG 51 class destroyers presently under contract.

These projects were evaluated on the basis of several criteria including project size, manageability, required level of effort breadth of scope, duration, significance in relationship to other shipyard projects and affordability. The project had to be small enough to be manageable, i.e., the size of the effort had to be such that if obstacles were encountered there would be some flexibility in managing the impact on resources and other projects in the shipyard. A significant emphasis was placed on the need for shipyard control of the design and product delivery process. It was recognized that if external constraints were too rigid, either in terms of product specifications or contractual requirements, that the potential benefit of the project would be compromised. Counter-balancing the need for manageable size was the need to have the scope and nature of the project recognizable as a significant undertaking in terms of complexity, technical challenge and importance to the shipyard. It was desirable that the duration of the project be relatively short in order to produce measurable and -identifiable results. The overriding constraint in all cases was that potential projects had to be funded and approved by senior management.

As expected, none of the candidate projects met all of the above criteria. The most difficult criteria to balance was the need for significance versus the desire for short duration. Of the significant shipbuilding projects considered, all were expected to span more than a year's time, due to the basic nature of large shipbuilding projects - size, complexity and level of

effort - and the fact that contracts with specific commercial customers had yet to be developed.

A meeting was held in December, 1993, at which BIW managers met along with the NSRP Applications team to decide which of the candidate projects would become the CE pilot. At this meeting it was decided that the recently awarded MARITECH design project offered the best prospects for successful implementation. Factors which favor the selection of this project include it is recognized as significant work for the shipyard, external constraints are manageable, risk to other ongoing projects is minimal, scope is broad, involving all phases of ship design and construction, and funding had been obtained.

A key issue on which a compromise had to be reached was the probable duration and scheduled start of actual CE implementation relative to the desires of the NSRP. It had initially been desired that the pilot be complete within one year from the start of the NSRP project. In the case of the selected CE Pilot, the duration of the project would necessarily be prolonged due to the relationship between it and the larger MARITECH "focused development project" through which it is funded. The MARITECH focused development project involves not only the development of multiple ship designs but also development of facilities modernization plans, commercial ship financing plans and technology transfer between BIW and two foreign shipyards, Kvaerner Masa Yards (KMY) and Mitsui Engineering and Shipbuilding (MES). As such, the implementation plan schedule and duration of the CE pilot has had to adjust to fit within the framework of these other activities.

MARITECH FOCUSED DEVELOPMENT PROJECT

The objective of the MARITECH focused development project at BIW is to achieve re-entry into the commercial shipbuilding market. The last commercial ships built at BIW were delivered in 1983. Product development efforts since that time have focused almost exclusively on military combatants for the U.S. Navy. As previously alluded, the MARITECH project focuses on developing essential capabilities in all areas of the ship design and production process necessary to re-enter the commercial market. These areas include: design, construction, facilities, human Resources, contracts and financing.

The first step in this effort has been the definition of specific capabilities and technologies required in each of these areas. This has been approached by conducting in-depth studies of two world leading shipbuilders, Kvaerner Masa Yards (KMY) and Mitsui Engineering and Shipbuilding (MES). Several teams of individuals representing all functional areas of the company were involved in bench-marking of these two companies. A total of 45 BIW employees were involved in these

exercises. The result is a very broad and thorough understanding of the work methods, procedures, technical and administrative systems management practices and productivity at all levels of these two world -class shipbuilders.

The knowledge gained through these bench-marking exercises is being applied through a team effort coordinated by a Commercial Shipbuilding Project group comprised of representatives from all functional areas of the company. Members of this team, co-located within the shipyard, are responsible for developing ship designs, shipyard facilities plans, ship construction plans, marketing plans, contract and financing arrangements, human resource and training plans.

Obviously, ship designs and construction plans have no use if they do not serve a viable market with known prospective customers. One of the principals of CE is to involve the customer directly in the development of new product designs and delivery strategies. In the case of the MARITECH project, two prospective customers were identified at the outset. Both are ship operators that presently own and operate ships in the commercial vehicle transport trade. Both were approached and agreed to cooperate with BIW in developing the initial MARITECH project proposal and to participate as partners in the subsequent product development effort. The direct participation of the senior management, technical and operations staffs of these potential customers in the CE process has been essential to achieving the goal of direct and ongoing customer interface throughout the product development process. In addition, marketing surveys and participation in important industry conferences and technical symposia are also means that are being used to achieve this goal of the CE effort.

IMPLEMENTATION PLAN

The CE Pilot effort is broken down into several principal phases Team Selection, Team Training, Management Training, Product Delivery Strategy, 1st Ship Design, 1st Ship Production, 2nd Ship Design, 2nd Ship Production. ongoing and in parallel with this activity is the technology transfer between KMY and Mitsui previously described. The ships being designed are RoRo vehicle carriers. Each design has unique requirements in terms of required cargo capacity, handling and stowage capabilities, deadweight tonnage, service speed and limiting drafts.

Completed work on the CE Pilot thus far includes team selection, team training, management training and development of a product delivery strategy. Presently ongoing is the contract design for the 1st Ship Design. The initial phases of technology transfer with KMY are complete. Subsequent activity will involve on-site visits by members of KMY staff to BIW. The initial

bench-marking of MES took place during February of this year. On-site technology transfer will occur over the next several weeks at MES. Subsequent activity with MES will be determined based upon the outcome of these next on-site visits.

TEAM ORGANIZATION

As discussed earlier, there is as yet no established organizational model from within the shipbuilding industry to follow in determining the composition of a shipyard CE team. Reported U.S. shipyard CE experience has focused primarily on "enabling technology" - CAD product models, distributed databases, document and work flow management systems - as opposed to CE team organization. This is also true with respect to foreign shipyards which have, for the most part not adopted a formal CE approach in their product development processes, at least insofar as establishing CE team organizations distinct from the line organization.

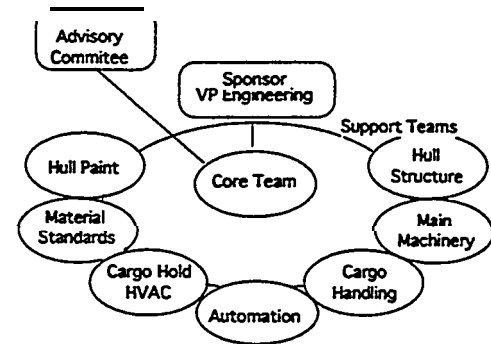


FIGURE 6 - CE PILOT TEAM ORGANIZATION

The "core team," "support team" organizational approach is being applied in the CE pilot-at BIW. A core team has been formed to provide overall guidance and direction to the project effort. Support teams have been formed to coordinate and consolidate support from within the line organizations. Figure 6 depicts this structure. Core team members have "custodial" responsibility for representing, interacting with and directing support team activities.

In addition to the team structures, a senior management sponsor and advisory council have been designated to provide oversight, accountability and direction to the core team. The role of these groups in the CE process are further described below.

CE TRAINING

Training of the CE team is an essential element of implementation. In BIW'S case, considerable effort had been made over the past several years to provide broad-based training in team problem solving techniques. In-house training programs include one to three day courses providing instruction in team process orientation management leadership and specific matters relating to the ongoing transition from trade to multi-disciplinary work teams in production. This training can provide useful background for participants in a CE process, however, it provides only one of several skill sets that are essential to a competitive product development team. Beyond basic technical design and team problem solving skills, development of skills in the following areas is considered to be essential

- Analysis of Competitive Environment
- Strategic Design
- Innovation
- Process and Product Measurement
- Team Dynamics Measurement
- Interpersonal Interaction

Extensive training material has been developed and is available from CERC and the Institute for Competitive Design (ICD), Rochester, Michigan to instruct product development teams in these areas. The ICD program has been applied in the training of product development teams at over 300 companies world-wide. As one of the NSRP project tasks, BIW agreed to apply the ICD method and to evaluate its effectiveness in preparing the CE pilot team.

The agreed upon training program was planned during a visit by Mr. Bart Huthwaite of ICD to BIW in December 1993. It focused on three areas: 1) management training, 2) product development team training, and 3) facilitating development of a Vehicle Carrier product Delivery Strategy

The product development team training program and exercises are explained briefly in the following sections.

MANAGEMENT TRAINING

Management training began with the initial visit of Mr. Huthwaite to BIW in December, 1993, in which he conducted a CE orientation briefing in conjunction with the bench-marking exercise previously described. This briefing covered the basic principals of CE and included an hour long question and answer session in which many organizational and procedural issues were discussed. A second management training session was held on March 8, 1994. This session included members of the pilot product development team as well as Mr. Huthwaite. The product development team presented the results of the training workshop, described later, in

which they had participated. Another important element of this session was an evaluation of management confidence level in the existing product development process. The intent of this exercise was to establish a baseline against which to measure the effectiveness of the CE implementation effort. This evaluation included strategic perspective, speed, cost awareness, quality and efficiency of present product development efforts. In each of these areas, four to five specific questions relating to performance of present product development efforts were asked. Managers rated corporate performance on a simple scale of one to ten. The overall results indicated a less than satisfactory perception of the existing product development process.

PRODUCT DELIVERY STRATEGY

The development of a "product delivery strategy" within the context of a CE process is very similar to the exercise of developing a "build strategy." The actual process involved is described below as part of CE product development team training. The result of this process is a 30-50 page document which spells out specific product attributes, metrics, action plans and responsibilities for accomplishing the development of a new product. The development of this document took place over a period of four days, from August 5-8, 1994, in which members of the product development team including ship owner's representatives and representatives from all internal BIW division participated. This process culminated in the presentation of the product delivery strategy to senior management

Specific results of this effort will be presented at the industry-wide CE workshop planned for June, 1994, in Bath, Maine.

PRODUCT DEVELOPMENT TEAM TRAINING

Training of CE product development team, comprised of both core and support team members, was conducted by Mr. Huthwaite from January 12- 15 at BIW. Between 25 and 30 BIW employees participated throughout a period of four days. The purpose of this effort was to provide thorough understanding of the fundamental skills required of product development teams, and to provide hands on experience in the application of these skills through a series of hands-on exercises. Specifics of Mr. Huthwaite's method are described in *STRATEGIC DESIGN: A GUIDE TO MANAGING CONCURRENT ENGINEERING* [13]. In general, the format for these sessions follows a set sequence that begins with explanation of a particular technique by Mr. Huthwaite followed by discussion involving the entire group, break-up of the group into working teams, application of technique to a sample problem, presentation of results by each team, and

critique of results by the entire group. For the purposes of training the group was given the task of designing a simple mechanical device. Initially, the device chosen was one used by Mr. Huthwaite with many training groups over a long period of time. By exercising its skills in designing this simple device, the group was able to compare its results with the results of many other groups facing the same challenge. The comparisons, needless to say, were quite intriguing. The group also worked with a sample design problem representative of that which would be encountered in a typical ship design situation. The chosen example was a down-flooding device to be used in refrigerated cargo holds wherein the device would serve as an effective barrier against the pressure, temperature and humidity differences between two adjacent cargo holds as well as function reliably as a cross connection in the case of flooding.

Analysis of Competitive Environment

For a product development team to be effective, it must have a clear understanding of the competitive environment in which it operates. This environment is characterized by

- customer's needs including
 - functional requirements
 - price expectations
 - performance expectations
 - schedule demands
- current competitive products available or under development in the market place
- external and internal constraints including
 - available capital resources
 - available technology
 - safety and environmental regulations
 - other legal or political restrictions
- internal strengths and weaknesses including
 - available skills and experience
 - shipyard tooling, facilities and capacity
 - proven capability in the market place

By tasking the product development team to analyze the competitive environment the entire team is driven to define and focus attention on what are the most important problems to be solved in the design process. In general, it is more important at the outset that the team be working to solve the right problems, as opposed to working to immediately solve any particular problem right

An effective strategy being employed by the BIW CE pilot team is to observe the operations of ship types similar to that which is to be designed. Direct discussions with ship operating crews, port facility operators as well as ship owners are essential to

understanding the competitive environment in which the ship will operate. Comprehensive data regarding the port restrictions, usage fees, insurance fees, operating and maintenance costs, crew skill, qualifications and experience are being sought. Industry trade journals and reports of pertinent regulatory agencies have been reviewed, compiled, analyzed and condensed. A strategic goal of this effort is to consolidate a technical library of ship designs to serve as design performance benchmarks in the development of new ship designs.

To understand its own competitive strengths and weaknesses, it is necessary for a company to view itself from the outside looking in. Bench-marking of competitors is one way to gain this perspective. Considerable recent research and attention have been devoted to analyzing the general competitive strengths and weaknesses of the U.S. shipbuilding industry. This work can serve as a useful starting point in developing techniques for analyzing and quantifying its own specific strengths and weaknesses. The use of consultants to obtain a third party opinion may also be of benefit.

Strategic Design

The analysis of the competitive environment provides a rational basis for defining specific fictional attributes of the new product design. Traditionally, these attributes are described in an outline specification developed by the marketing department in conjunction with a potential customer. In a CE process, other shipyard departments are involved in this process through participation in the product development team. In the CE process, the definition of product functional attributes is not limited to just external customer requirements, but is expanded to include the requirements of internal "customers" as well. The result is a set of requirements that reflects the company's strengths and capabilities and that ultimately leads to achievement of the highest quality within the competitive constraints of the market.

The process of defining product attributes in a team environment is quite straightforward. The team divides into groups, the groups compose lists of attributes, the attributes are categorized, evaluated against the company's strengths, internal and external constraints, ranked in priority order and finally selected by the team to be either included or excluded. The objective of this effort is to identify the eight most important competitive attributes of the product. These eight will become the basis for future measurement of product success. One important criteria in the selection of these attributes is that each attribute must be quantifiable in terms of some measurement of the product design, e.g., cargo deadweight capacity or the number of structural parts are both measurable attributes of a ship design.

For each product attribute, three measurements or metrics are initially identified 1) the current design

value, 2) the minimum or threshold value considered to be acceptable and 3) the objective value or competitive goal.

For a complex product such as a ship, the idea that there should be only eight attributes of the design considered “most important” created a great deal of controversy within the pilot product development team. To resolve this controversy, the technique used was to broaden or categorize the definition of the eight most important competitive attributes, and to discretely specify attributes and associated measurements within each broad category. Thus, a broad category such as maintainability could be identified as a critical product attribute but quantified in terms of several more discrete attributes such as overhaul and dry-docking interval, underway maintenance tasks, crew size, number of required spares, etc.

The essential benefit of this exercise is that it focuses the team’s attention on the attributes which are most important to the success of the product design, and provides quantifiable goals for the measurement of the design in process.

Another important outcome of this process is the definition of the “step”, “stretch” and “leap” versions of a product, representing the present version, the next incremental evolution and the future long term vision of a product. The product development team should be encouraged to look beyond present constraints and/or limitations to envision how future versions of the product will evolve. In the marine industry, for example, future requirements for safety, environmental protection, automation, etc., can be expected to have significant impact on ship capabilities. The objective of developing a design strategy is not only to identify and quantify competitive attributes of the present version of a product but to identify and plan for future development and improvement of the product. The ultimate goal is to provide for such development and future upgrade of the product in the present design.

Innovation

The core technical skill of the product development team is its ability to innovate and develop cost effective technical alternatives to achieving strategic design goals. In world-class product development teams, this is accomplished by iteration of multiple alternative designs and rational evaluation of those designs based upon criteria that measure the total cost impact of their distinguishing attributes. It is essential that the product development team understand the total cost impact of alternative designs. This includes understanding the principals of producible designs and developing the ability to map and evaluate the process impact of alternative design solutions. In the CE process, the core team effort is initially focused on developing the technical solutions to the eight top priority competitive product attributes. In latter stages, support teams

should also apply this methodology in developing detail design of subsystems and components.

The principals elements of process based design include

- reducing numbers of parts
- simplifying manufacturing processes
- simplifying product Structure/architecture
- identifying and eliminating hidden costs.

Part number reductions can be achieved either through the greater use of “common” or “standard” components, by parts “implosion” or simply eliminating parts. Standardization is not a subject that is new to the U.S. shipbuilding industry, however, by comparison the U.S. industry clearly has a way to go in achieving the level of standardization typical of world leaders. One of the most successful strategies employed by industry leaders is the use of multi-functional materials, i.e., materials that can be substituted or applied in a variety of situations. The use of high strength steel in lieu of mild steel for equipment foundations to avoid having to stock two different grades is a good example. Parts implosion is the technique of creating a single part to accomplish the same function as previously accomplished by a number of parts. The familiar case of using stanchions to both support grating and pipe running beneath the grating is an example of part implosion. A simple example of parts elimination would be the use of shallower deck stiffening which eliminates the need for reinforcing collars in way of stiffener penetrations through web frames and bulkheads.

Process simplification is achieved in a number of ways including the elimination of process steps through simplification of the product design, and the reduction of variability and precision required in the manufacturing process. Examples of highly variable processes typically involved in shipbuilding include welding, compound curvature in plate forming and compound bends in pipe bending. Designs that make use of modularity or repeatability will by definition have fewer process steps than otherwise. Design for assembly is also a technique for eliminating process steps in the assembly process. This is typically exploited in shipbuilding by designing for on-block and on-unit installation.

Simplification of product architecture means reducing the variety of technologies applied in production. This is the corollary to reducing the number of process steps. The objective is to simplify part geometry, eliminate sophisticated material forming and joining technologies, high precision/low tolerance machining, fitting, measuring and aligning. The use of poured chocks for instance is an example of a simplified product architecture for the mounting of a complex piece of equipment

Eliminating hidden costs means identifying the various processes such as marshaling, staging, handling, tooling set-up, surface preparation and cleaning, testing, inspecting and documenting, required to enable the production of a product. The evaluation of hidden cost is often the most difficult challenge facing the product development team. The involvement of production personnel in the product development process is essential to making well informed evaluation of the indirect costs incurred on the shop floor.

Product and Process Measurement Skills

The total cost associated with a given design is identified and understood by thoroughly examining the process steps involved in the production of that design. Many techniques have been devised to enable such analysis, including Quality Function Deployment ICD/FOCUS methodology, Taguchi Methods, Boothroyd Dewhurst's Product Design for Assembly, GE/Hitachi Assemblability Evaluation Method and Lucas Engineering's Design for Assembly. A summary of these methods and further bibliography is provided in *DESIGN FOR COMPETITIVENESS*, by Huthwaite, 1992.

In evaluating the total cost of alternative designs, it is essential to include not only the direct labor and material cost, but also the indirect or hidden cost. The ICD/FOCUS methodology accomplishes this through a common sense approach. The method enables the CE team to quickly and comprehensively identify the process steps involved in supply, pre-production, production and post-production stages of the product life cycle. All significant cost contributors are identified including numbers of parts and part numbers, manufacturing technologies, *process* steps and indirect costs or processes. An index is calculated based on the material cost, the number of parts, the number of part numbers (i.e., different parts), the number of pre-production and production process steps and the level of precision, variability and risk associated with the processes. This type of analysis, while time consuming, results in a rational basis for evaluating design alternatives.

A representative list of the design issues to which such techniques are being applied by the CE pilot team include:

- basic hull structural framing system and frame spacing alternatives
- structural assembly breakdown and hull block size alternatives
- hull form alternatives including flat bottom versus deadrise and faired versus knuckled bulb and skeg
- deck stiffening alternatives including bulb flats versus angle bar

- main deck girder construction including box versus tee sections
- cargo hold liner and decking material alternatives
- hoistable deck and ramp arrangement alternatives
- main engine selection and installation alternatives
- piping material alternatives
- hull paint system alternatives

Team Organization and Decision Making

To ensure effective buy-in and participation of the line organizations, the BIW CE pilot team was carefully chosen to include the individuals that will carry a large portion of the responsibility for implementing the decisions made through the team process. The CE pilot team's relationship with the line organization is maintained through each organization's respective representative on the team. The team member has responsibility to inform the line organization manager of decisions affecting his area of responsibility. The line manager must concur with respect to the general functional, procedural and regulatory requirements to be met by the design. Cost and performance objectives must also be agreed upon. These requirements are defined and articulated within the 'Product Delivery Strategy' alluded to earlier. The team has latitude to make decisions as long as the decision fits within the boundaries of the framework defined by the Product Delivery Strategy.

Accountability

The key issue with regard to empowering the CE team is the accountability of the team and *interaction* between the team and management. The core team must be accountable. In the present CE pilot the collective accountability of the team is to its senior management sponsor, the VP of Engineering. Overall goals and objectives are set by a senior management advisory or steering committee comprised of company Officers and directors.

The frequency upon which these groups interact is important in setting the pace for the effort of the CE team. In the present case, the pilot team meets formally with the team sponsor about once per month. The Senior Advisory Committee meets on a quarterly basis.

As alluded to earlier, each core team member is accountable to both the product development team leader and the respective line functional manager whom he/she represents. At present, it is expected that both line manager and team leader will have input to the team member's performance evaluation.

Communications

One of the principal advantages sought in the formation of a product development team is improved communications and coordination of effort amongst team members. Collocation of team members is often viewed as a requisite to effective team formation and communications. BIW has thus far employed collocation as a strategy in the pilot implementation. An office facility has been provided wherein core team members are collocated. Additional space is available for the temporary use of support team members, visiting owner's representatives, subcontractors and/or suppliers.

It has been found thus far that collocation in and of itself does not assure improved communications unless accompanied by an effective team process, pro-active participation of the individuals assigned to the team and support from the line organization. Communications between the team and the line organization is just as important as is intra-team communications. There is presently a direct line of communication between each team representative and the managers of that member's respective line functional division. Meetings between team members and line managers must be encouraged to be frequent and spontaneous.

Interpersonal Skills

To measure and assess the effectiveness of the team process, the BIW CE pilot team has been trained in a method of team dynamics measurement. This technique is simple in concept. The team decided upon a number of measures of effectiveness including

- Technical Skill
- Decision Making Process
- Efficiency
- Open Minded Spirit
- Leader/Team Interaction
- Communications
- Individual Involvement
- Sense of Accomplishment

The CE pilot team presently conducts its own self evaluations on the basis of these factors. Team members rank team performance in several areas within each of the above categories on a scale of one to ten. The results are compiled and summarized by an individual outside the team organization to ensure objectivity and anonymity if desired. The team meets as a group to review the results and to address performance issue and decide upon connective action.

Tools and Enabling Technologies

The CE pilot team has been encouraged to seek and apply tools and technologies which best suite its goals,

needs, level of expertise, background and familiarity. The use of proven technology has been encouraged both within the team and on the part of BIW management. Advanced geometric modeling, and naval architectural design tools have been in use for some time and are being actively employed by the team. Thus far, the application of new technology has included advanced ship structural design optimization systems and the use of state-of-the-art statistical and computational fluid dynamics systems for performing hull form and propulsion trade-off studies. It is expected that these technologies will have a significant influence on the product development team's capability to perform a greater number of iterations on a design within a shorter period of time.

The CE pilot team has a long term objective to review, analyze and recommend new enabling technologies that can benefit future product development efforts. This objective is being pursued through the foreign shipyard bench-marking exercises and through direct contacts with suppliers. Thus far the focus has been on evaluation of integrated shipbuilding and design systems.

RESULTS AND CONCLUSIONS

The purpose of the CE pilot at BIW is to prove the validity and benefit of CE as an approach to new product development. The pilot effort is still ongoing at BIW, so it is as yet too early to reach any final conclusions regarding these matters. To date, the CE pilot effort has been given the endorsement and support of senior management and has thus far succeeded in sustaining support of middle management ship owners and individual participants. A significant amount of work has been accomplished by a small number of individuals in developing the contract design for the 1st vehicle carrier. The ultimate success of this effort will in large part be measured by the success of the product development team in obtaining a contract with the ship owners. A further report of this project will be made at an industry-wide workshop to be held at BIW in June of 1994.

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